

Modern Physics

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Based on Foundations of Modern Physics

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9-1 Structure of Solids

In our everyday world we see matter in three phases: gases, liquids, and solids. In a gas the average distance between two atoms or molecules is large compared with the size of an atom or molecule. The molecules have little influence on one another, except during their frequent but brief collisions. In a liquid or solid the atoms or molecules are close together and exert forces on one another comparable to the forces which bind atoms into molecules. (There is a fourth phase of matter, plasma, which occurs only at very high temperatures, inside stars and in the laboratory. A plasma is a gas of ions and electrons. The properties of a plasma are very different from those of an ordinary gas because of the long-range electrical and magnetic effects arising from the charges of the particles.) In a liquid, the molecules form temporary short-range bonds which are continually broken and reformed as a result of the thermal kinetic energy of the molecules. The strength of the bonds depends on the type of molecule. For example, the bonds between helium atoms are very weak van der Waals bonds, and He does not liquefy at atmospheric pressure until the very low temperature of 4.2 K is reached.

If a liquid is slowly cooled, the kinetic energy of its molecules is reduced and the molecules will arrange themselves in a regular crystalline array, producing the maximum number of bonds and leading to a minimum potential energy. However, if the liquid is cooled rapidly so that its internal energy is removed before the molecules have a chance to arrange themselves, a solid is often formed that is not crystalline but resembles a "snapshot" of a liquid. Such a solid is called *amorphous*; it displays short-range order but not the long-range order (over many atomic diameters) characteristic of a crystal. Glass is a typical amorphous solid. It is characteristic of the long-range ordering of a crystal that it has a well-defined melting point whereas an amorphous solid merely softens as its temperature is increased. Many materials may solidify in either an amorphous or a crystalline state, depending on how they are prepared. Others exist only in one form or the other. Most common solids are polycrystalline—i.e., they are collections of single crystals that exhibit long-range order over many atomic diameters. The size of such single crystals is typically a fraction of a millimeter; however, large single crystals occur naturally and can be produced artificially (Figure 9-1). We shall discuss only simple crystalline solids in this chapter.

The most important property of a single crystal is its symmetry and regularity of structure: it can be thought of as a single unit structure repeated throughout the solid. The smallest unit of a crystal is called the *unit cell*. The structure of the unit cell depends on the type of bonding between the atoms, ions, or molecules in the crystal. If more than one kind of atom is present, the structure will also depend on their relative size. The bonding mechanisms are those discussed in Section 8-1: ionic, covalent,

Amorphous solids and crystals



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Figure 9-1
Single quartz crystal